Autogenerering af hydrostratigrafiske modeller fra boringer og SkyTEM

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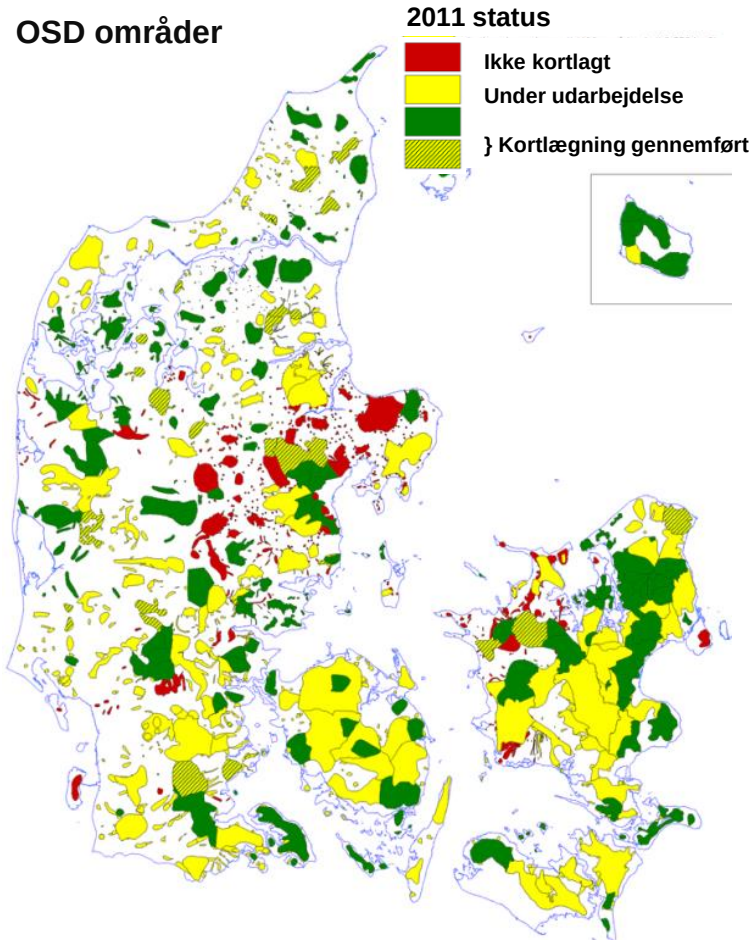
DTU Environment
Department of Environmental Engineering

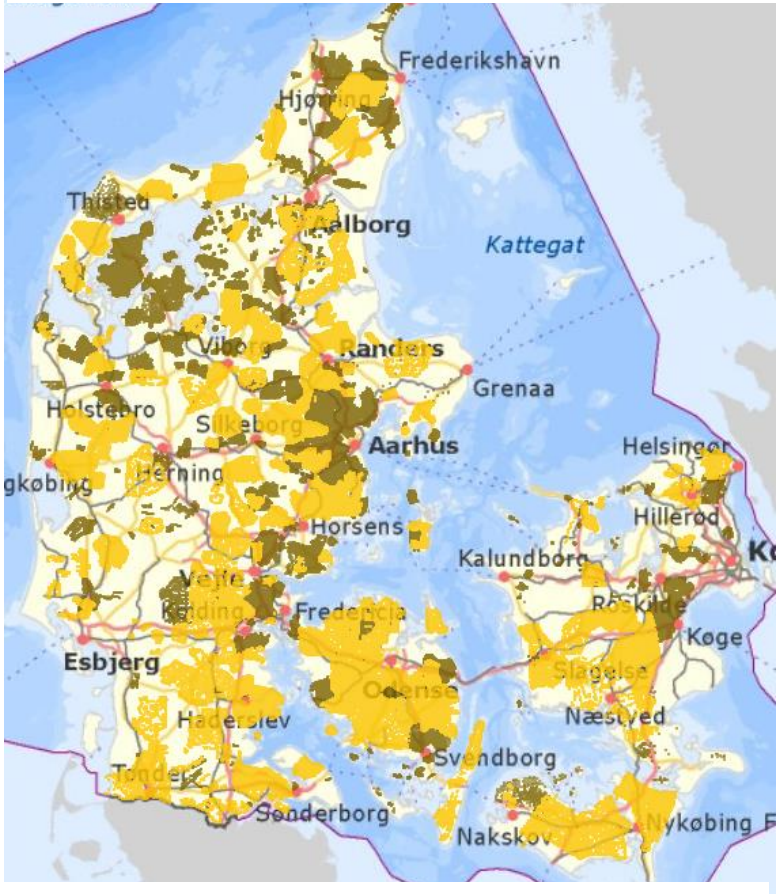
EM data og grundvandsmodeller

OSD områder



http://gk.geus.info/xpdf/20110624-faglige-resultater-2010-med-omslag-endelig.pdf

TEM og SkyTEM sonderinger, GERDA 04 November 2014



Brun er TEM, gul er SkyTEM

Motivation

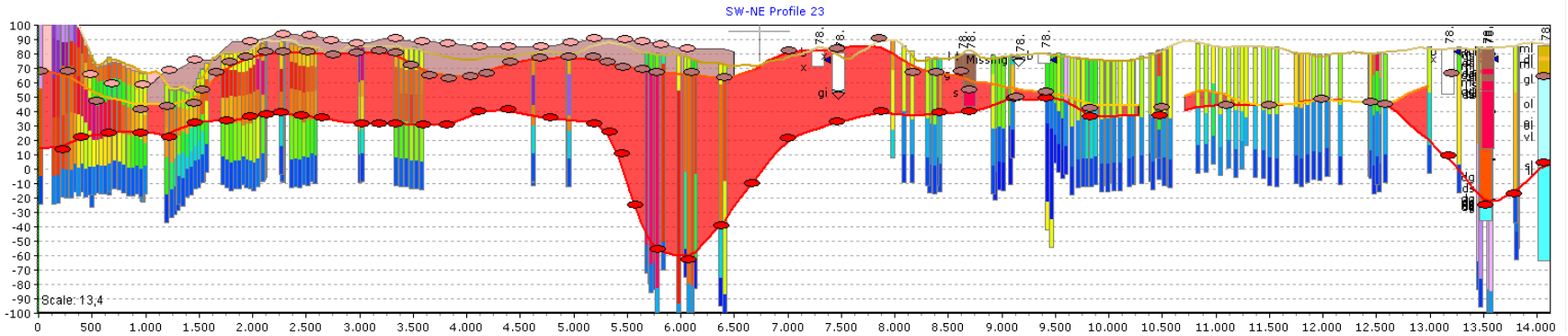
- **Forvaltning af grundvandsressourcer**
  - Grundvandsudnyttelse
  - Forurening
  - Indvindingsoplande

- **Strukturel geologisk usikkerhed** er den dominerende usikkerhedskilde I grundvandsmodellering

- **Prædiktioner** fra grundvandsmodeller er følsomme overfor ændringer i den hydrostratigrafiske model

- Grundvandsmodeller er **non-unique'e** i forhold til hydrostratigrafien

Hydrostratigrafisk modellering



- Rumlig komplekst
- Geologiske modeller er subjektive
- Strukturel usikkerhed ikke kvantificerbar

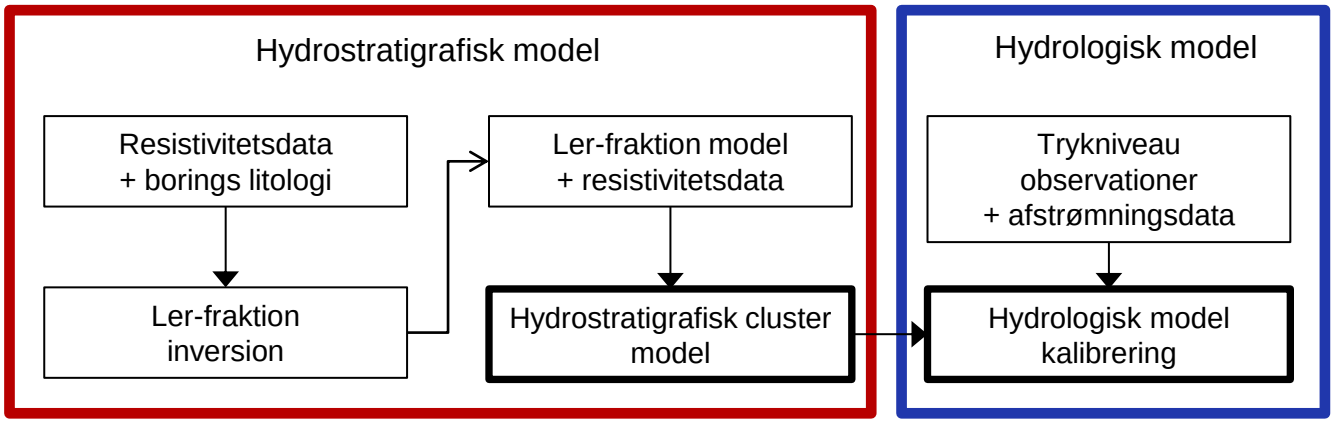
Metode

Geofysisk og lithologisk data → **struktur**

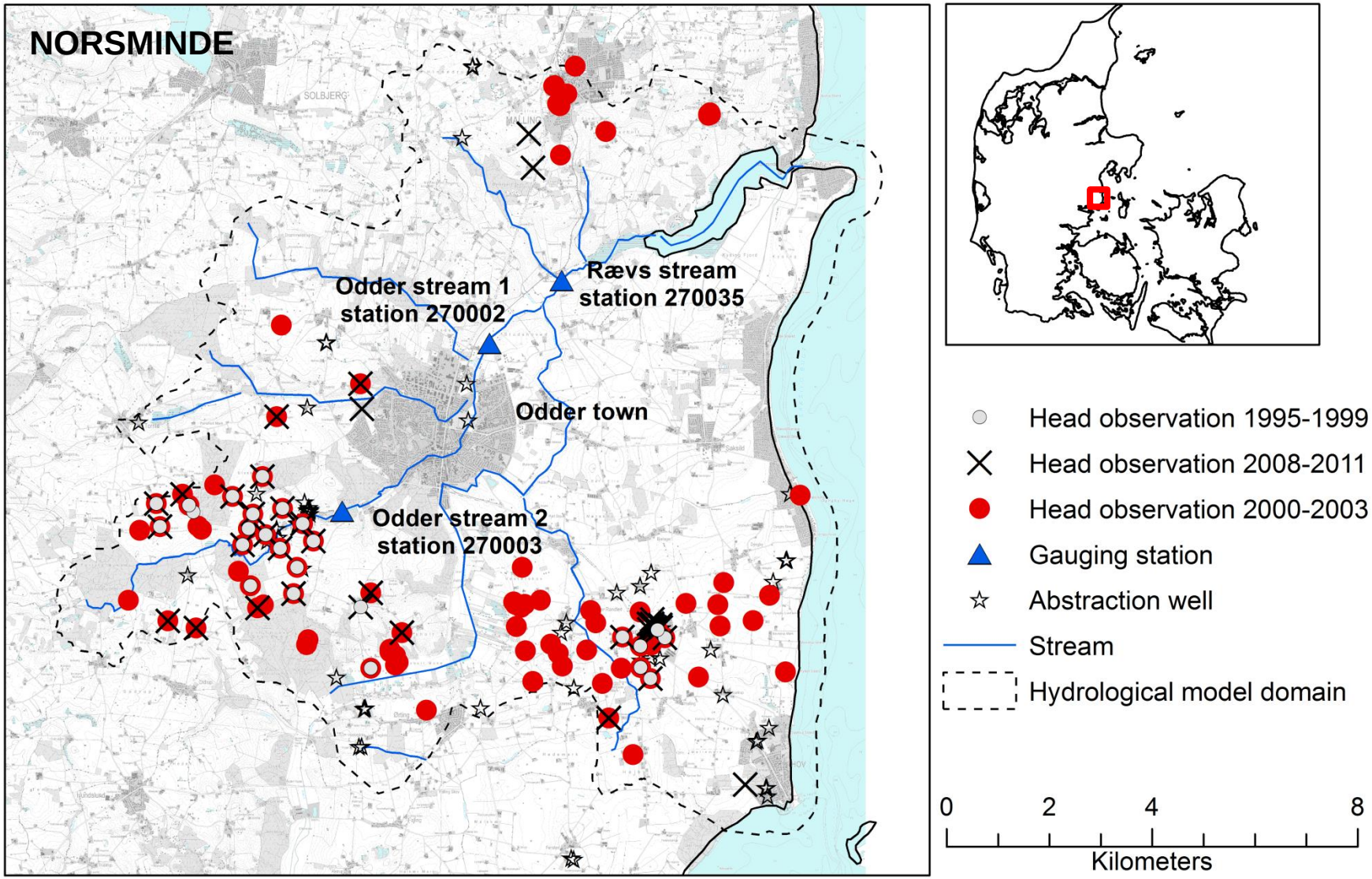
- Ler-fraktion inversion
- Cluster analyse

Hydrologisk data → **hydrauliske parametre**

- Hydrologisk model kalibrering

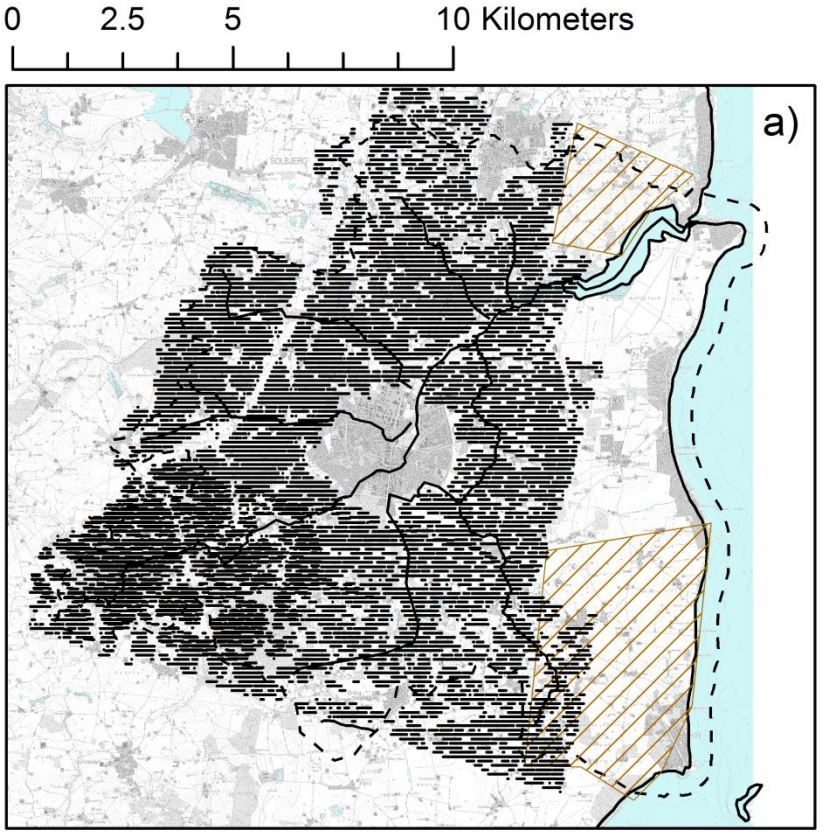


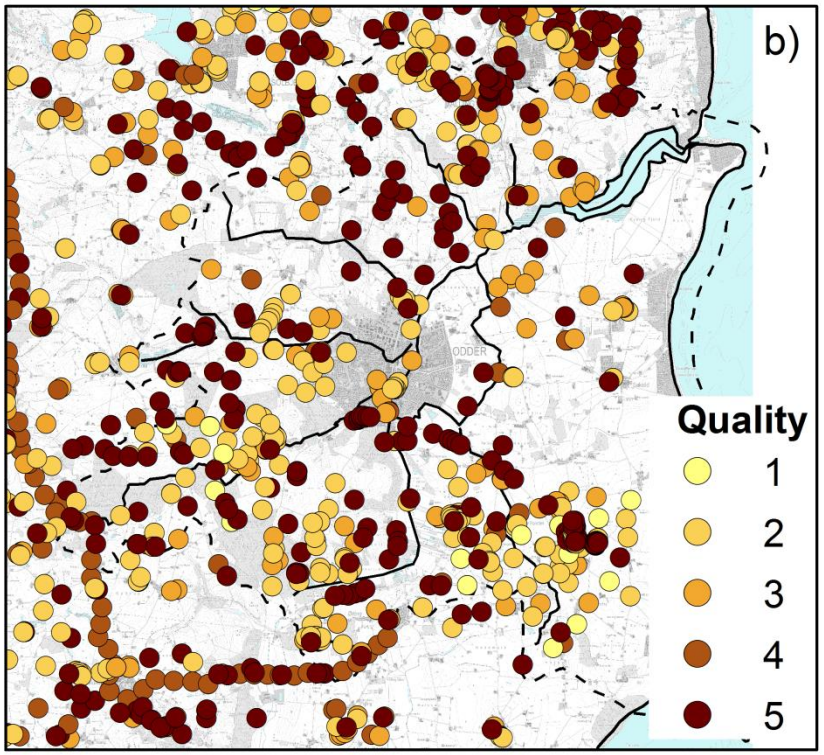

http://xn--oplandsrd-norsminde-fjord-jfc.dk/oplandet/


NORSMINDE
Odder stream 1
station 270002
Rævs stream
station 270035
Odder town
Odder stream 2
station 270003
Head observation 1995-1999
Head observation 2008-2011
Head observation 2000-2003
Gauging station
Abstraction well
Stream
Hydrological model domain
0
2
4
8
Kilometers

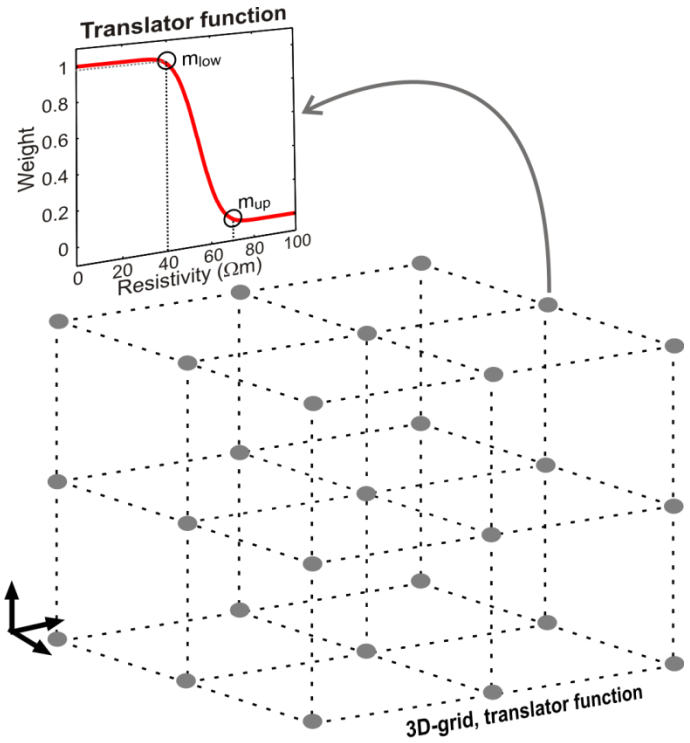
TEM (skraveret brun) og
SkyTEM (sorte punkter)

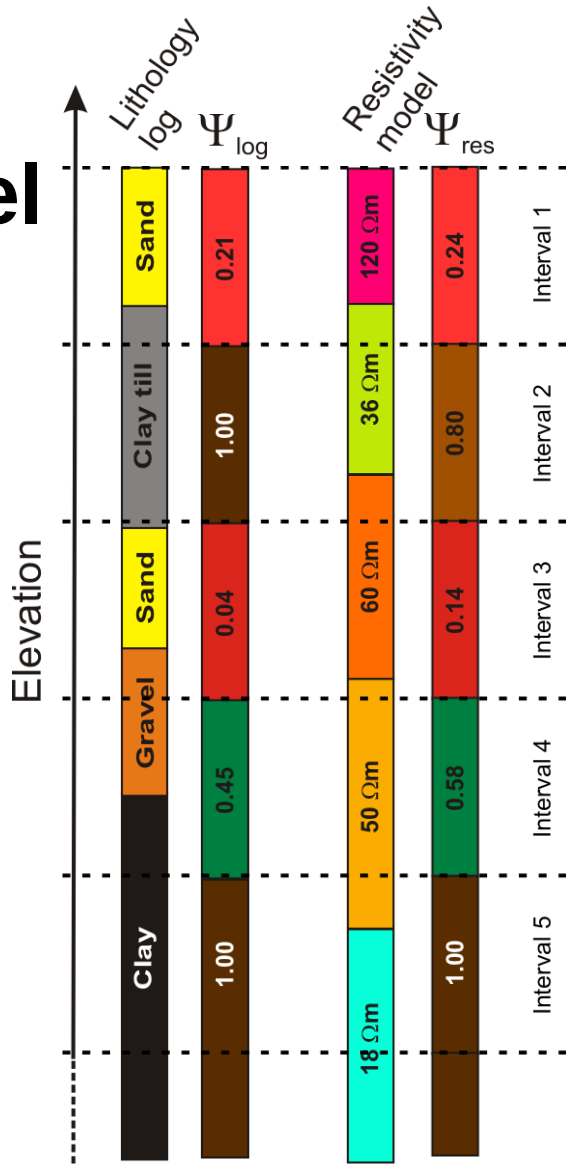
Litologiske boringer

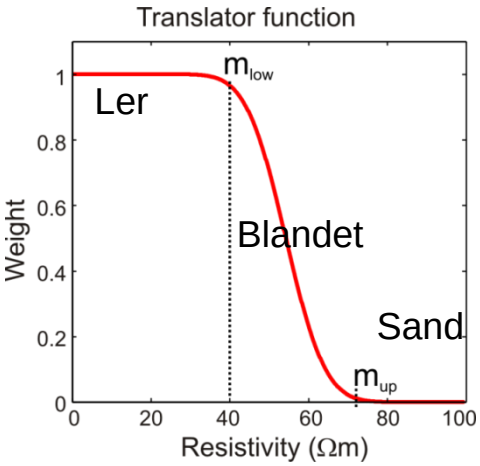




Ler-fraktion model

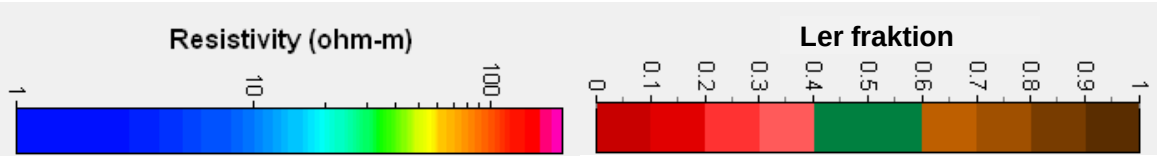


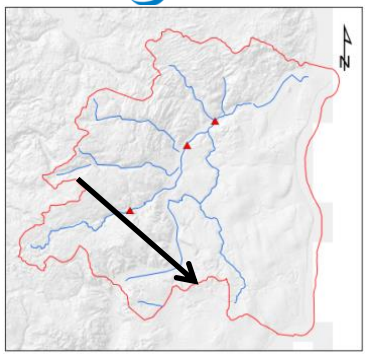


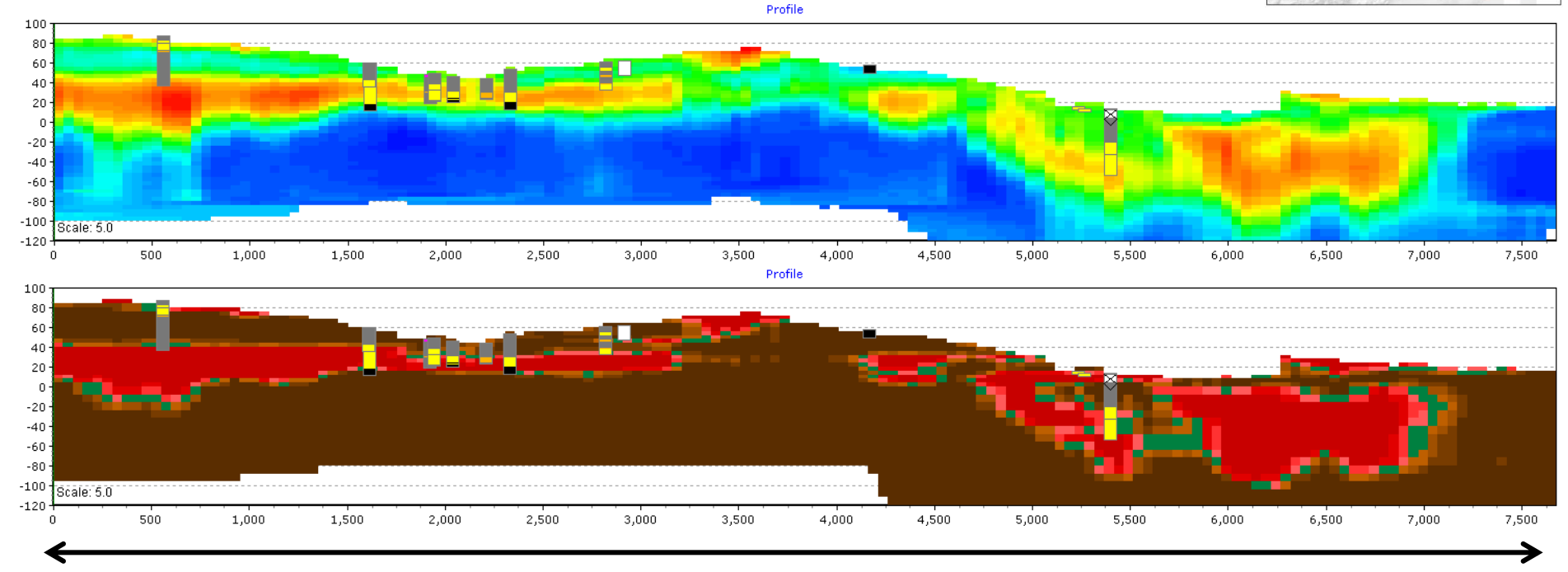


Foged, N., Marker, P. A., Christansen, A. V., Bauer-Gottwein, P., Jørgensen, F., Høyer, A.-S., and Auken, E.: Large-scale 3-D modeling by integration of resistivity models and borehole data through inversion, Hydrol. Earth Syst. Sci., 18, 4349-4362, doi:10.5194/hess-18-4349-2014, 2014.

Resistivitets- og ler-fraktion model

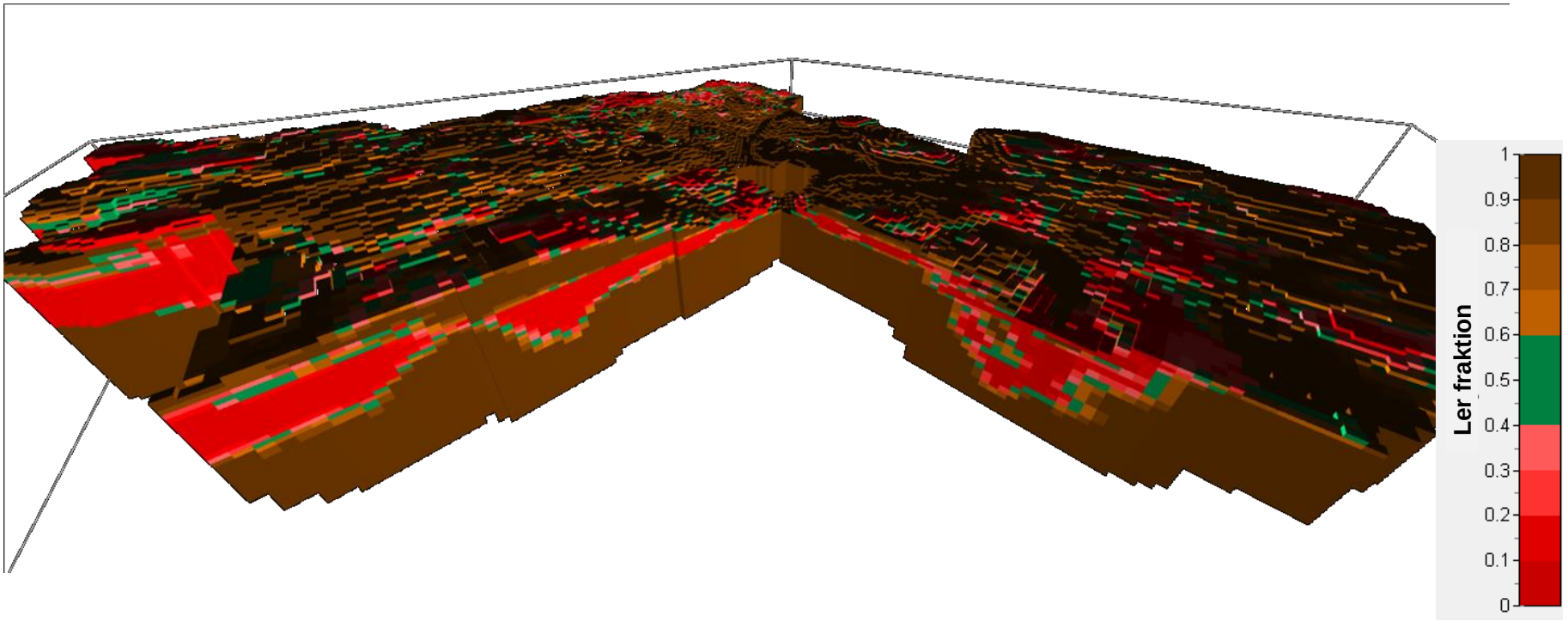






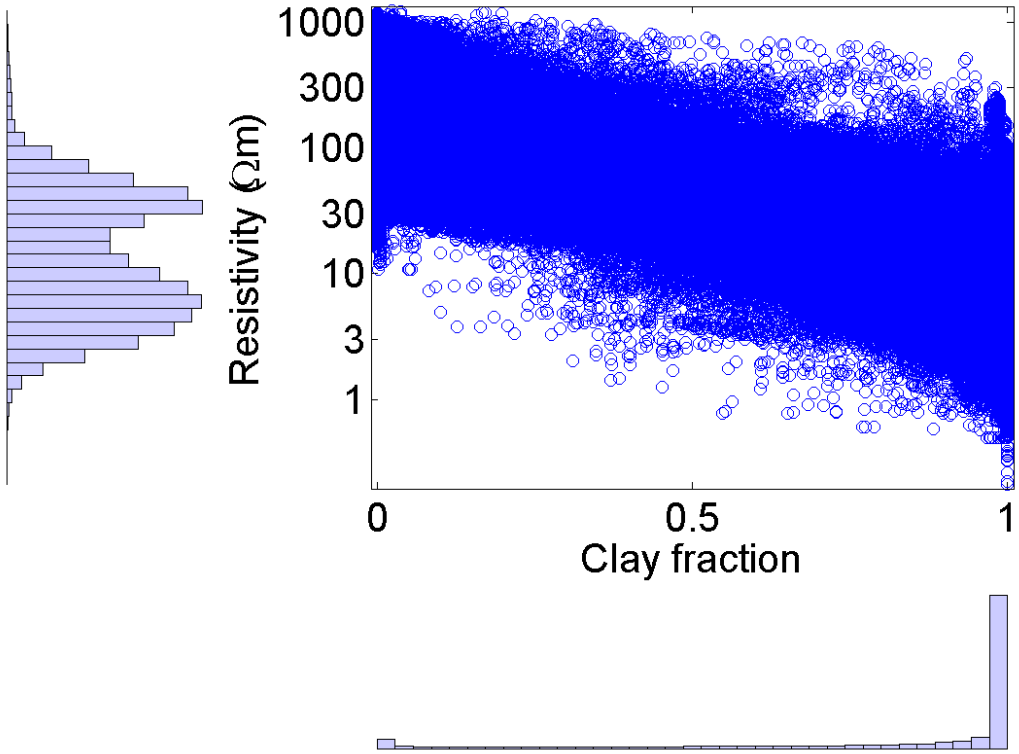
7.5 km

3D ler-fraktion model

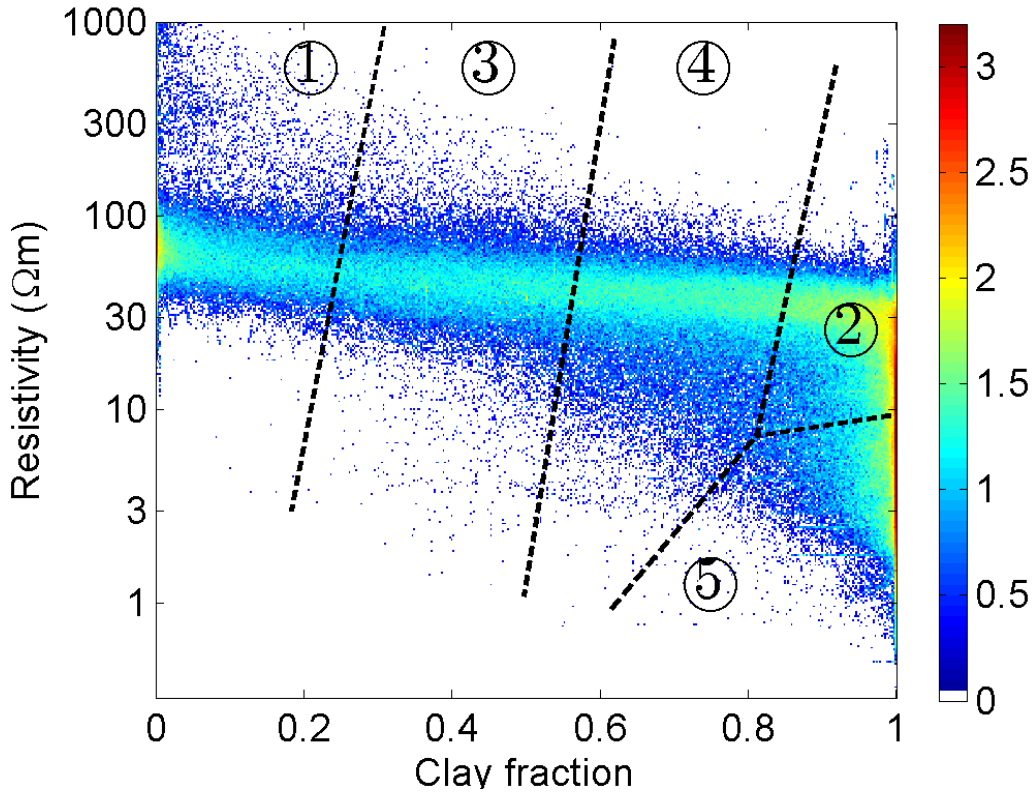


K-means cluster analyse

- Inddeling af undergrunden i zoner
- Information i resistivitetsdata og ler-fraktion værdier

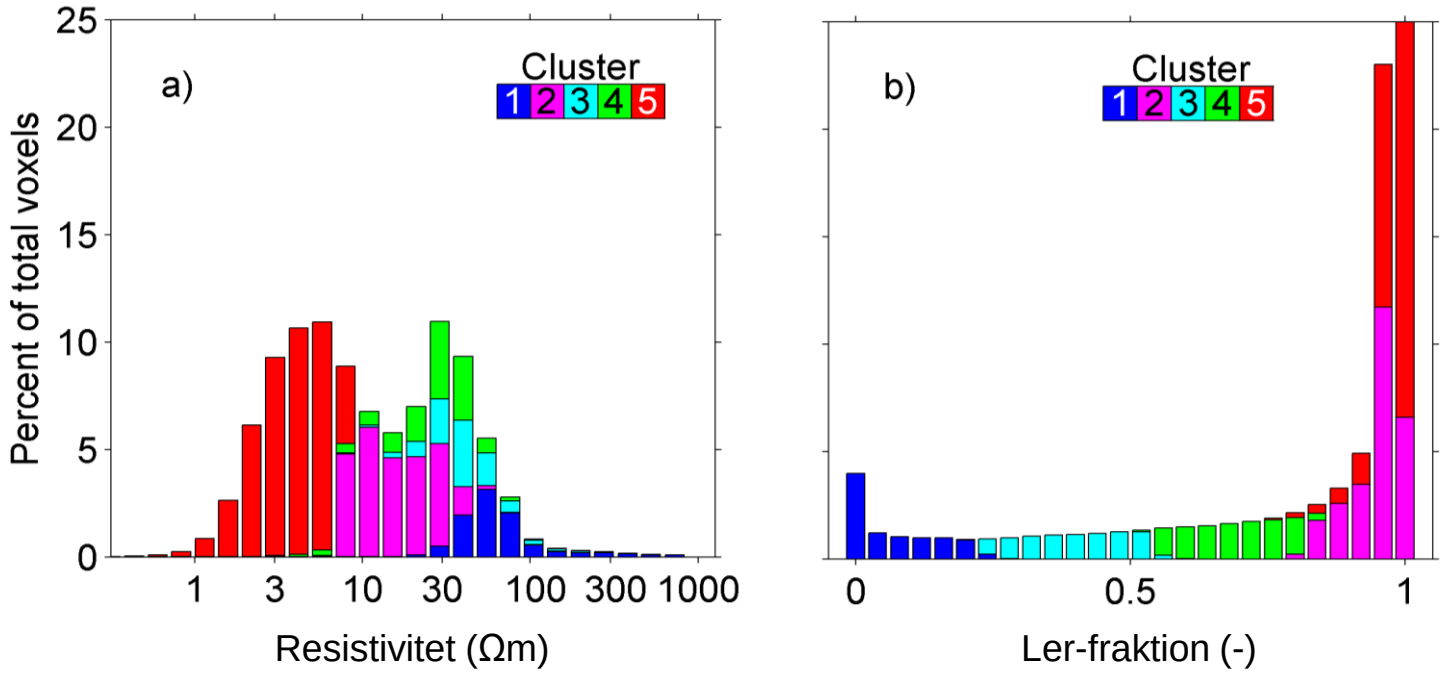


Inddeling af datarum

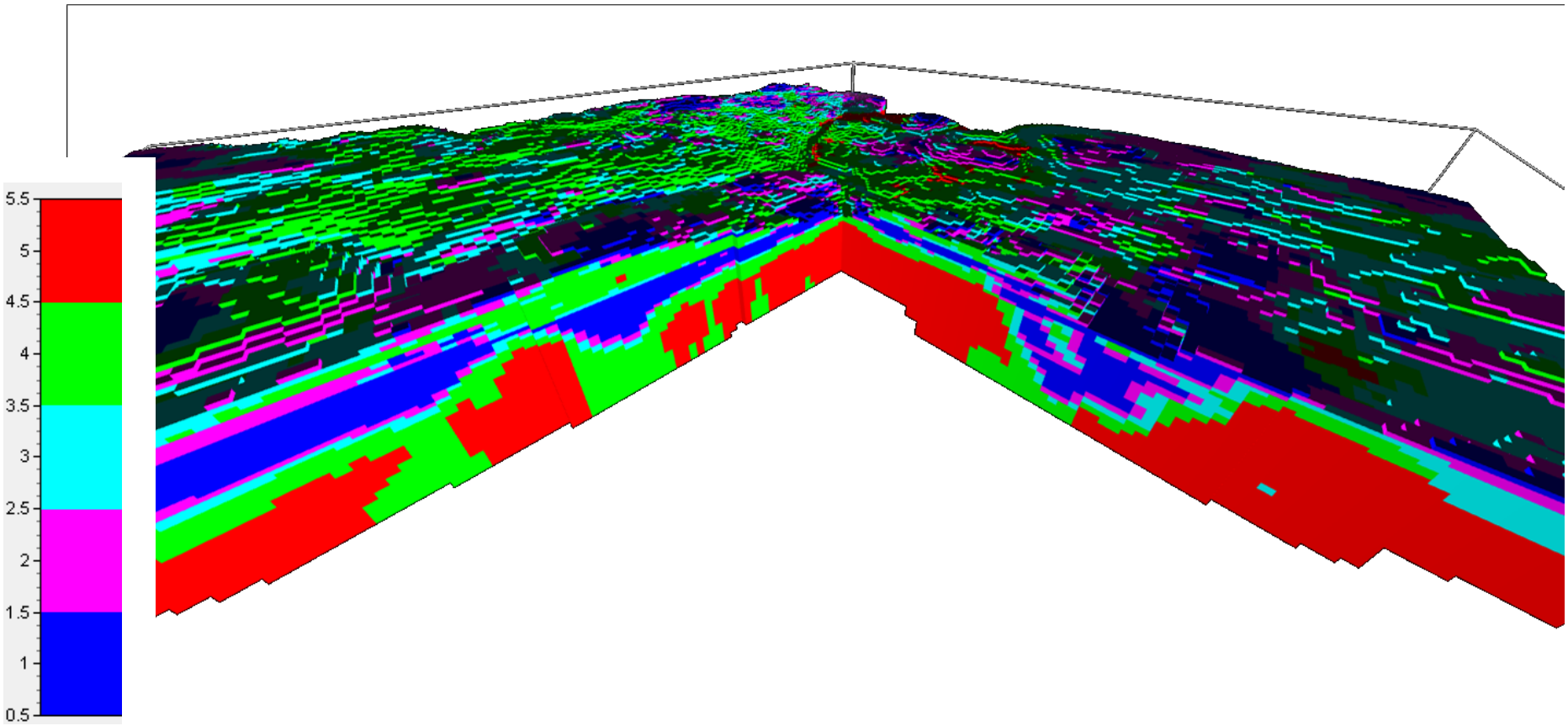


Farveskala angiver antal datapunkter (logaritmisk)

Cluster-model



3D cluster-model



Integreret hydrologisk model

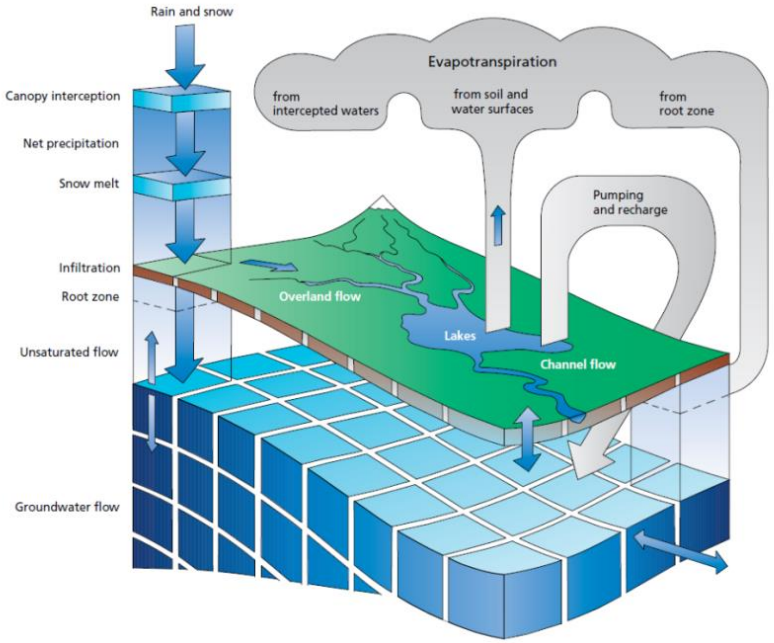
MIKE-SHE model

Hydrologisk forcing

- Daglig klima data
- Grundvandsindvinding

Observationer

- Trykniveau
- Vandføringer



Kalibrering af hydrologisk model

$$\Phi = \Phi_{head} + \Phi_{discharge} = w_{H,i} \sum_{\mathrm{i=1}}^{\mathrm{N_H}} \left(\frac{\mathrm{obsH_i} - \mathrm{simH_i}}{\sigma_{\mathrm{H}}} \right)^2 + w_{D,i} \sum_{\mathrm{i=1}}^{\mathrm{N_D}} \left(\frac{\mathrm{obsD_i} - \mathrm{simD_i}}{\sigma_{\mathrm{D},i}} \right)^2$$

σ_{H}	std dev trykniveau
$\sigma_{\mathrm{D},i}$	std dev vandføring
$w_{H,i}$	subjektiv vægt, trykniveau
$w_{D,i}$	subjektiv vægt, vandføring
$\mathrm{N_H}$	antal trykniveau observationer
$\mathrm{N_D}$	antal vandføring observationer
obs	observeret
sim	simuleret

Performance kriterier

$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}(\mathrm{obs_i} - \mathrm{sim_i})^2}$$

Spredningen på residualerne

$$\mathrm{RMSE_w} = \sqrt{\frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\frac{\mathrm{obs_i} - \mathrm{sim_i}}{\sigma_i}\right)^2}$$

Vægtet RMSE; hvis = 1 er data fitted til én standardafvigelse

$$\mathrm{ME} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}(\mathrm{obs_i} - \mathrm{sim_i})$$

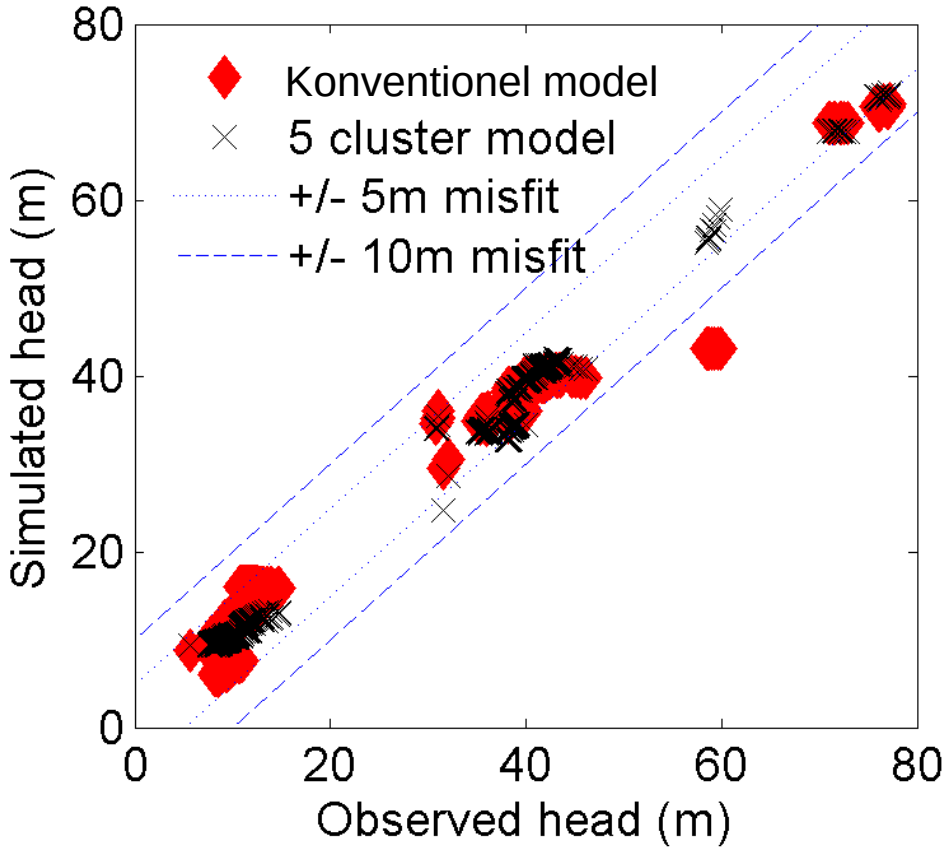
Middelfejl; mål for bias

Benchmarking

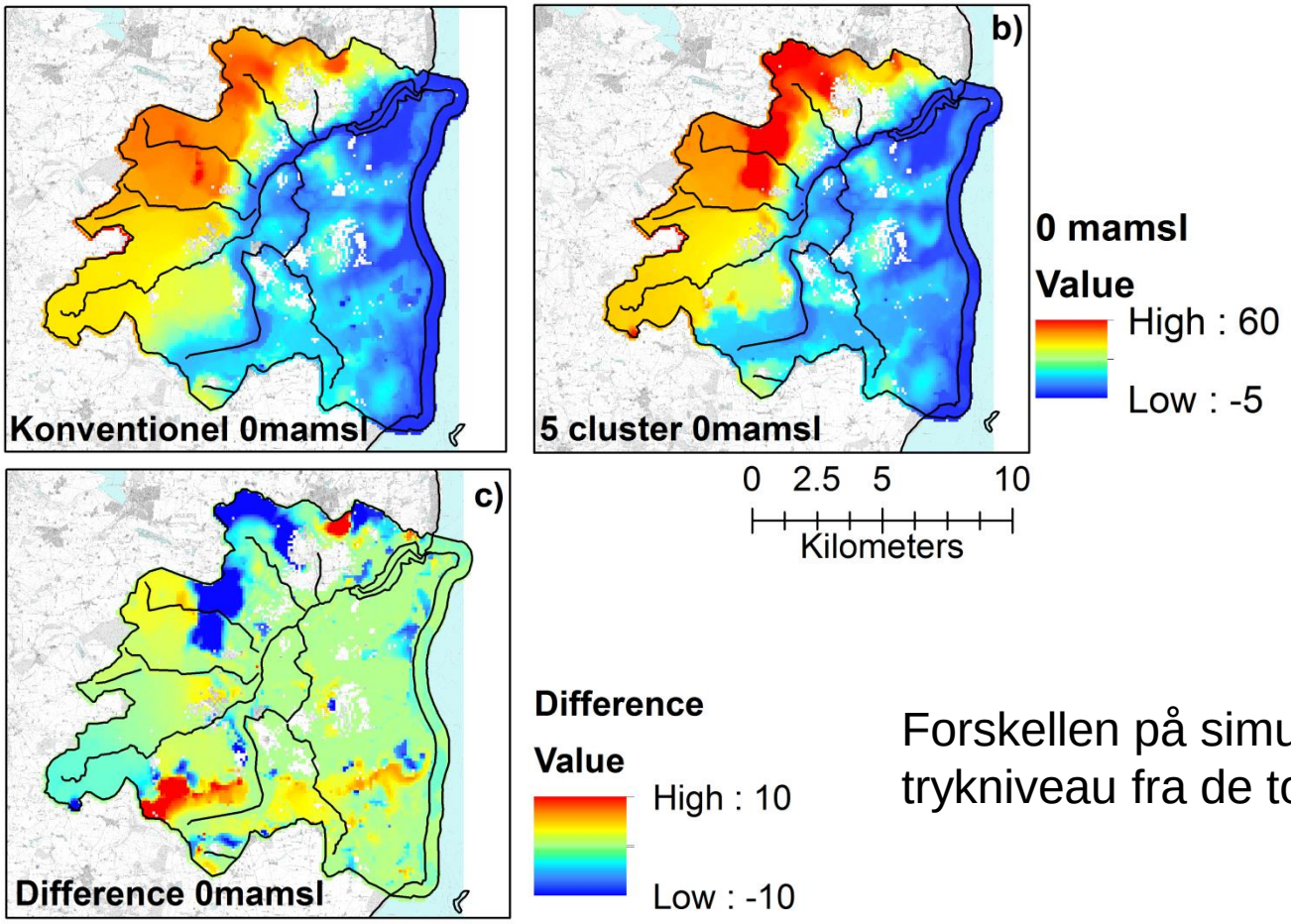
- 5-cluster model performance sammenlignet med konventionel hydrostratigrafisk model

		Konventionel model			5-cluster model		
		Weighted RMSE (-)	RMSE	ME	Weighted RMSE (-)	RMSE	ME
Calibration 2000-2003	Head (m)	**2.81**	**3.27**	**-0.0762**	**2.14**	**2.57**	**0.00310**
	Discharge (m^3/s)	0.326	0.267	-0.0259	0.338	0.278	-0.0107
Validation 1995-1999	Head (m)	2.85	3.24	-0.926	1.76	2.19	-1.01
	Discharge (m^3/s)	0.446	0.180	-0.0501	0.524	0.203	-0.0354
Validation 2008-2011	Head (m)	3.27	3.97	-0.899	2.64	3.34	-1.28
	Discharge (m^3/s)	0.501	0.124	-0.0853	0.526	0.120	-0.0809

Simuleret trykniveau, 1995-1999

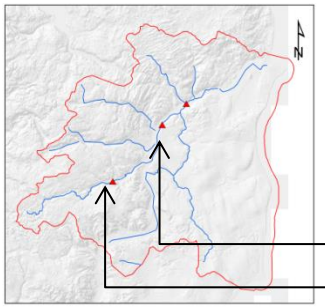


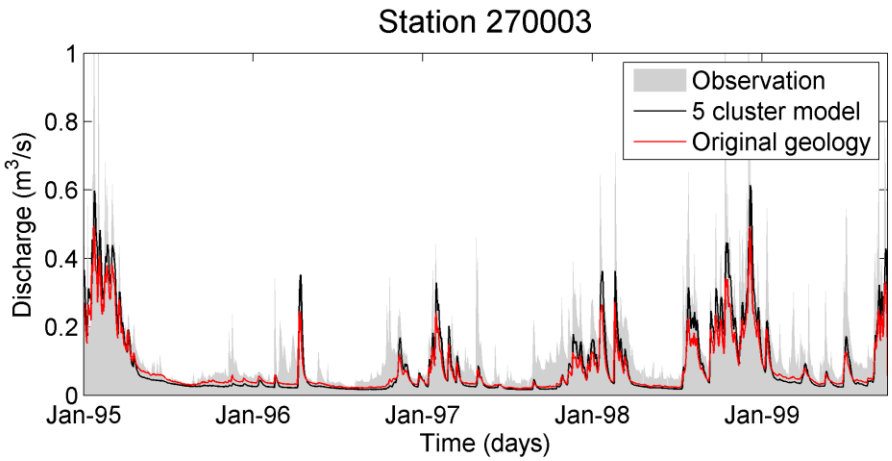
Simuleret trykniveau, kote 0m

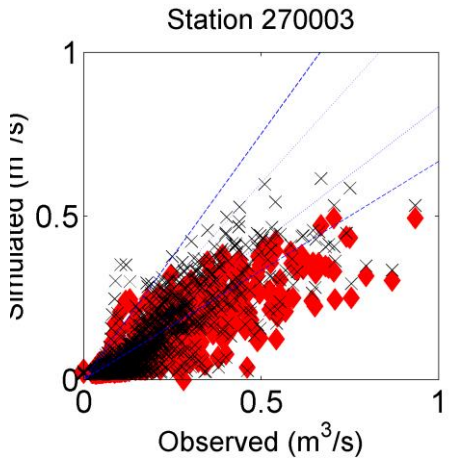


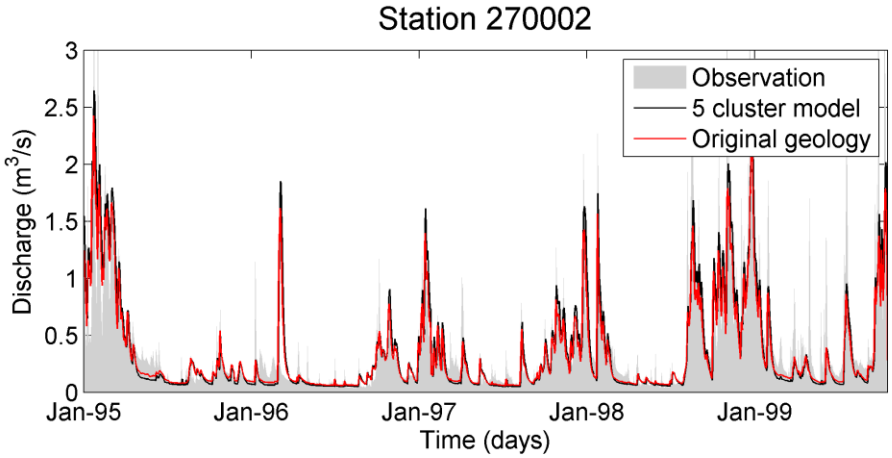
Forskellen på simuleret trykniveau fra de to modeller

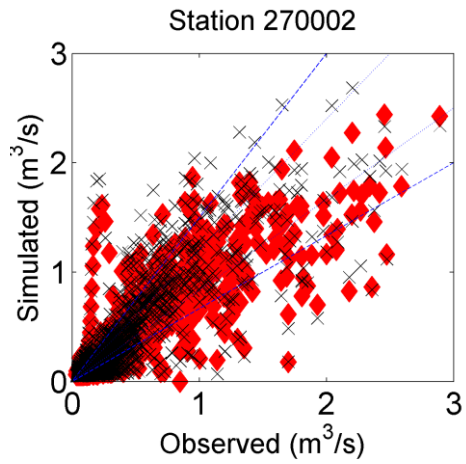
Afstrømningsdata 1995-1999



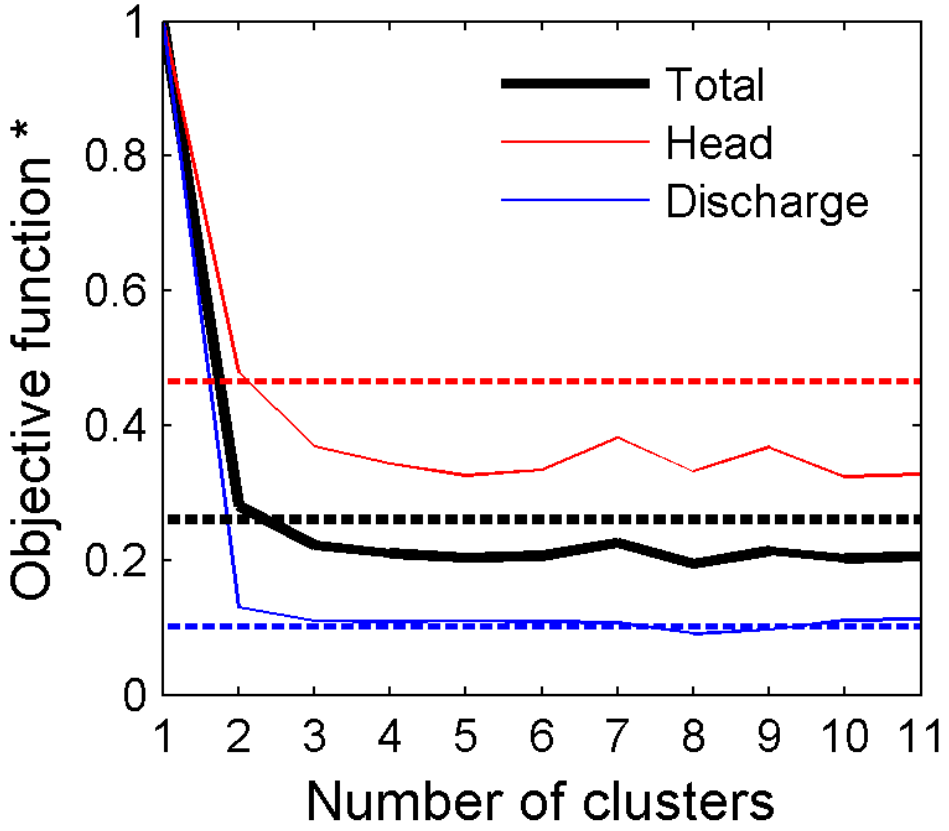








Hvor mange zoner?



Cluster modeller

Konventionel model

Konklusion

- Vi kan ud fra geofysisk resistivitetsdata og ler-fraktion model inddele undergrunden i zoner, hvis hydrauliske ledningsevne kan estimeres i hydrologisk kalibrering
  - Resultat sammenligneligt med konventionel hydrostratigrafisk model
- Semi-automatisk og drevet af data → mindre ressourcekrævende
- Udnyttelse af rumlig information i geofysikken
- Mulighed for metodestandardisering i hydrostratigrafisk modelopbygning

Fortsættelse

- Usikkerhedsanalyse ved generering af ensemble